ORGANIC CARBON, NITROGEN AND THE STABILITY OF SOIL AGGREGATES IN AREAS CONVERTED FROM SUGAR CANE TO EUCALYPTUS IN THE STATE OF ALAGOAS[1]

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ABSTRACT – The conversion of areas cultivated with sugarcane into eucalyptus forests can promote improvements in the physical, chemical and biological properties of the soil. Within this context, the aim of this study was to evaluate the changes in the stocks and levels of carbon and nitrogen and soil-aggregate stability in an area of transition from sugarcane to eucalyptus in the State of Alagoas, Brazil. The study was carried out on a rural property, located in the district of Atalaia. The systems under evaluation consisted of four areas, one cultivated with sugarcane for approximately 20 years, taken as the reference area for the study, and three adjacent areas cultivated with eucalyptus forest, at 1, 3 and 6 years of age. Bulk density, the levels and stocks of carbon and nitrogen, and the soil aggregation index were all determined. The conversion of a sugarcane plantation under conventional tillage with straw burning into eucalyptus plantations promoted an increase in the levels and stocks of carbon and nitrogen in the soil; it also reduced bulk density and increased the water stability of aggregates. The results show that the conversion of sugarcane into eucalyptus in the Atlantic Forest region of Alagoas may be an alternative for promoting carbon sequestration and improving soil quality.

Keywords: Carbon sequestration; Soil quality, Forest plantations.

CARBONO ORGÂNICO, NITROGÊNIO E ESTABILIDADE DE AGREGADOS DO SOLO EM ÁREAS DE CONVERSÃO DE CANA-DE-AÇÚCAR PARA EUCALIPTO EM ALAGOAS

RESUMO – A conversão de áreas cultivadas com cana-de-açúcar para florestas de eucalipto pode promover melhorias nas propriedades físicas, químicas e biológicas do solo. Neste contexto, objetivou-se com este trabalho avaliar as mudanças nos estoques e teores de carbono e nitrogênio e na estabilidade de agregados do solo em área de transição de cana-de-açúcar para eucalipto em Alagoas. O estudo foi realizado em uma propriedade rural, localizada no município de Atalaia - AL. Os sistemas avaliados consistiram de quatro áreas, sendo uma cultivada com cana-de-açúcar, por aproximadamente 20 anos, tomada como a área de referência do estudo; e três áreas adjacentes, cultivadas com floresta de eucalipto a 1, 3 e 6 anos. Foram determinadas a densidade do solo, os teores e estoques de carbono e nitrogênio e os índices de agregação do solo. A conversão do cultivo de cana-de-açúcar com preparo convencional e queima da palhada para plantações de eucalipto promoveu o aumento dos teores e estoques de carbono e nitrogênio do solo. Também reduziu a densidade do solo e aumentou a estabilidade de agregados em água. Os resultados indicam que a conversão de cana-de-açúcar em eucalipto na região da Mata Atlântica de Alagoas, pode ser uma alternativa para promover o sequestro de carbono e melhorar a qualidade do solo.

Palavras-Chave: Sequestro de carbono; Qualidade do solo; Plantações de florestas.

1. INTRODUCTION

Brazil is the world's largest producer of sugarcane, with an estimated production for the 2016/17 crop of 694.54 million tons (Conab, 2016). In the northeast of Brazil, the State of Alagoas is important as the main producer, this being its principal economic activity. However, in recent years this activity has been losing ground to other agricultural crops, mainly due to a devaluation of up to 17 and 27% in the price of ethanol and sugar, respectively (Conab, 2016), and to competition from states in the Centre-South. Within this context, eucalyptus is one of the agricultural crops that are emerging in the state as an option for diversifying agricultural production. It is estimated that the area currently planted with eucalyptus in the country is 7.4 million hectares (IBGE, 2017), with almost all of this area having been planted in areas of pasture; in Alagoas however, eucalyptus is being adopted as a substitute for sugarcane cultivation.

In addition to supplying wood, eucalyptus plantations contribute to soil carbon (C) sequestration, due to less anthropogenic influence, high biomass production and continuous deposition of plant residue on the surface. These factors contribute to an increase in soil organic matter (SOM) and consequently to the maintenance of organic carbon (OC) sinks (Ibiapina et al., 2014). It is said that eucalyptus plantations, when properly managed, can store between 50 and 400 Mg C ha^{-1} (Pulrolnik et al., 2009; Pillon et al., 2011), however, the fixation and storage of C in the soil depends on various factors, such as, the type of soil, local climate conditions, cropping system and management. (Gatto et al., 2010; Ibiapina et al., 2014; Marques et al., 2016). Pegoraro et al. (2011) found significant changes in the stocks of C and nitrogen (N) in the 0-100 cm layer of areas of eucalyptus in relation to areas of pasture. Agreeing with these authors, Pulrolnik et al. (2009) found that cultivating eucalyptus promoted an increase in C stock in the more active fractions of SOM, in comparison to areas of Cerrado and pasture.

During the cultivation of eucalyptus, minimal soil turning and the maintenance of plant residue is important, since SOM deposited in the litter promotes the formation and stabilisation of aggregates (Loss et al., 2014), contributing to an increase in the C and N stocks in the soil (Conceição et al., 2017). According to Rossetti et al. (2014), the formation and stabilisation of aggregates presents a multiplicity of interactions between the physical, chemical and biological factors of the soil. In addition, it acts on the physical protection of the SOM, with the increase in aggregates being determined by the connection between the macroaggregates (>0.250 mm), the formation of microaggregates (<0.250 mm) and the fixation of C within the microaggregates (Loss et al., 2014). Vasconcelos et al. (2010), evaluating aggregation in a Yellow Latosol under sugarcane cultivation in Alagoas, found a reduction in aggregate stability in an area of sugarcane compared to native forest. Ibiapina et al. (2014), studying soil aggregation in areas of native forest, eucalyptus and soybean in a Yellow Latosol in the State of Piauí, found an increase in aggregate stability in areas of native forest and eucalyptus.

The dynamics of soil aggregation, and the levels and stocks of C and N, are influenced by the management systems (Barreto et al., 2014; Mascarenhas et al., 2017), however there is no information on the environmental impact of the transition from sugarcane to eucalyptus. The hypothesis of this study therefore is that adopting eucalyptus in areas cultivated with sugarcane (burnt system) favours the physical, chemical and biological attributes of the soil, since the management practices adopted in eucalyptus systems are less intensive than for sugarcane. Based on the above, the aim of this study was to evaluate the effect of converting from the cultivation of sugarcane to eucalyptus, on the stocks and levels of carbon and nitrogen and soil-aggregate stability in a Latosol in the Atlantic Forest region of the State of Alagoas.

2. MATERIALAND METHODS

2.1. Study area and sampling the soil

The study was carried out on a rural property in the Forest Zone of the district of Atalaia in the State of Alagoas, Brazil. The district is located in the Eastern Mesoregion of the state (09°26'56.6" S and 36°00'30.8" W). According to Köppen, the climate in the region is tropical warm (As'), with a mean annual temperature of 27°C and autumn/winter rainfall of between 1,000 and 1,500 mm, well-distributed throughout the year. The soil in the study area was classified as a clay-loam Latosol with a clayey texture (Embrapa, 2012).

The systems under evaluation consisted of four areas: an area of 5.0 ha, cultivated with sugarcane (Cane) for approximately 20 years, always under a conventional system of soil preparation, with straw burning and manual harvesting, and considered the original condition of the soil, and three adjacent areas, measuring 2.5, 3.0 and 1.5 ha, cultivated with eucalyptus forest at one (E1), three (E3) and six (E6) years respectively. The areas of eucalyptus had previously been cultivated with sugarcane under a conventional system for about 20 years. Preparation of the areas of eucalyptus was conventional, with liming incorporated by harrowing and deep subsoiling (80-100 cm), followed by base phosphate fertilisation; the eucalyptus seedlings (Clones 224 and 1407) were then transplanted into holes spaced 3.5 x 2.5 m apart.

Soil samples were collected in June and July of 2015 by opening five 90 cm trenches in each area. The trenches were opened randomly between the rows and considered as replications, giving a total of 120 samples. Disturbed soil samples (to evaluate C and N) and undisturbed soil samples (to evaluate aggregation) were collected between the planting rows at depths of 0-10, 10-20, 20-30, 30-40, 40-60 and 60-80 cm.

2.2. Soil analysis

The disturbed samples were air-dried, the lumps were removed, and the samples passed through a 2.00 mm sieve to give air-dried fine earth (ADFE). The total organic carbon (TOC) was determined by the wet oxidation method with $K_2Cr_2O_7$ 0.167 mol L^{-1} in a sulphuric medium using an external heating source. The excess dichromate, after oxidation, was titrated with ferrous ammonium sulphate solution $Fe(NH_4)_2(SO_4)_2.6H_2O$ 0.5 mol L^{-1} (Yeomans and Bremner, 1988). The total nitrogen (TN) was quantified by sulphuric digestion, followed by Kjeldahl distillation, as per Tedesco et al. (1995).

The stocks of C and N were calculated by multiplying the values for TOC, TN, BD and the soil layers, as per the equation: E = BD*A*Q, where E, is the stock of C or N in the soil (Mg ha^{-1}); BD, bulk density (g $cm^{-}3$); A, the thickness of the sampled layer (cm); and Q, the C or N content of the soil (%).

Particle size analysis of the soil was carried out using the pipette method, as per Embrapa (1997); the data for clay content are presented in Table 1. Bulk density (BD) was determined using the volumetric ring method (Embrapa, 1997).

To evaluate the distribution of water-stable aggregates, the method described by Embrapa (1997) was employed, which uses the following diameter classes: 4.76-2.0 mm, 2.0-1.0 mm, 1.0-0.50 mm, 0.50-0.25 mm and less than 0.25 mm, with the samples subjected to vertical agitation in a Yodder device. From the data for aggregate dry weight, the weighted mean diameter (WMD), geometric mean diameter (GMD) and aggregate stability index (ASI) were calculated according to the methodology proposed by Loss et al. (2014).

2.3. Statistical analysis

The study areas were selected taking into consideration the homogeneity of the soil characteristics, the relief and their relative proximity. The experimental design was completely randomised, with the treatments corresponding to the four cropping systems (Cane, E1, E3 and E6). The results were submitted to Bartlett's test for homogeneity and the Kolmogorov-Smirnov test for normality, followed by analysis of variance. In the case of a significant difference, the mean values of the treatments were compared by Tukey's test ($p < 0.05$). In addition, the data were submitted to multivariate analysis, more specifically to cluster analysis by the Tocher method (Rao, 1952), using the principal components retained for interpretation, applying the mean Euclidean distance as a measure of dissimilarity (Corrêa et al., 2010).

3. RESULTS

The values for BD varied little in the layers of each cropping system, with the highest values in the 0-10 cm layer for all of the systems under evaluation. In the set of results, the values found ranged from 1.44 to 1.13 g cm^{-3} ($p < 0.05$). The Cane and E1 systems had the highest values for BD in each of the layers studied, with no statistical difference between the systems; however, the BD in E1 differed significantly from the E6 and E3 systems in the 0-10, 10-20, 20-30 and 40-60 cm layers. In the 0-10 cm layer, E1 had a significantly higher BD when compared to the E3 and E6 systems. Under the Cane system, the values for BD differed significantly only from those of E6 in the 40-60 and 60-80 cm layers (Table 1).

The agricultural system and the depth influenced ($p < 0.05$) the stocks of SOC and TN (Table 1). In general, the Cane and E1 systems had the largest reductions in soil C and N stocks when compared to E3 and E6. The greatest losses in N stock were seen in the 30-40 cm layer, where the stocks were reduced by 61.4,

Table 1 – Mean values for clay content, bulk density (BD), soil organic carbon (SOC) and total nitrogen (TN) for the different systems and depths under study.
Tabela 1 *– Valores médios dos teores de argila, densidade do solo, estoques de carbono orgânico do solo e nitrogênio total nos diferentes sistemas e profundidades estudadas.*

Layer(cm)	Cropping system			
	Cane	E1	E3	E6
		Clay (g dm^{-3})		
0-10	277.3	308.0	253.8	377.0
10-20	280.7	317.0	264.0	277.5
20-30	268.9	320.3	278.3	330.0
30-40	346.5	385.0	342.3	402.0
40-60	403.0	407.0	442.0	478.7
60-80	539.7	486.0	426.3	483.7
		BD (g cm^{-3})		
0-10	1.36 aAB	1.44 bB	1.29 aAB	1.22 aA
10-20	1.31 aAB	1.39 bB	1.26 aAB	1.20 aA
20-30	1.31 aAB	1.35 abB	1.19 aA	1.20 aA
30-40	1.34 aA	1.28 abA	1.26 aA	1.20 aA
40-60	1.28 aBC	1.37 abC	1.17 aAB	1.13 aA
60-80	1.36 aB	1.21 aAB	1.23 aAB	1.17 aA
		SOC (Mg ha^{-1})		
0-10	25.02 aB	29.03 aAB	30.70 aA	28.98 aAB
10-20	23.27 abA	23.52 bA	27.15 abA	25.17 abA
20-30	19.53 bcA	19.07 bcA	21.29 cA	21.79 bcA
30-40	16.06 cAB	12.81 dB	16.48 dAB	19.11 cA
40-60	24.00 abAB	21.10 bB	22.25 cAB	26.12 abA
60-80	19.40 bcB	14.46 cdC	24.77 bcA	18.47 cBC
0-80	127.3 A	119.9 A	142.64 A	139.6 A
		TN (Mg ha^{-1})		
0-10	1.11 aAB	0.91 aB	1.15 aAB	1.38 aA
10-20	1.10 aAB	0.85 aB	1.03 abAB	1.23 aA
20-30	0.65 bB	0.83 abB	0.70 cB	1.25 aA
30-40	0.71 bBC	0.49 abC	0.87 abcB	1.27 aA
40-60	1.29 bA	0.76 bB	1.20 cAB	1.06 bAB
60-80	1.02 bA	0.77 bA	1.13 cA	0.81 bA
0-80	5.88 C	4.61 D	6.08 B	7.00 A

Cane: sugarcane; E1: eucalyptus after one year, E3: eucalyptus after three years, E6: eucalyptus after six years. Mean values followed by the same uppercase letter in the rows and lowercase letters in the columns do not differ by Tukey's test at 5% probability.

44.0 and 31.4% under the E1, Cane and E3 systems respectively, compared to the area of eucalyptus after six years (E6).

Considering the complete layer of soil under study (0-80 cm), the highest value for C stock was found in E3 ($p<0.05$), with increases of 12.0, 18.9 and 2.1% when compared to Cane, E1 and E6 respectively. Also noteworthy was E6, which resulted in an increase in SOC stock of 25.5% in relation to the area of sugarcane (Table 1). For the N stock, the E6 system had the highest value, with significant increases ($p<0.05$) of 19.0, 51.8 and 15.1% compared to the Cane, E1 and E3 systems respectively (Table 1).

It can be seen in Figure 1 that there were decreases in the TOC content between the depths evaluated under all systems, showing the highest values in the first layers of soil under the E3 and E6 systems, but with a statistical difference for the 30-40 cm layer only. The lowest values for TOC and TN content were seen under the Cane and E1 systems for all the sampled layers. The greatest losses in TOC content were seen in the surface layer (0-10 cm), where the values found under the Cane and E1 systems showed reductions of 23 and 16% respectively when compared to E3; when compared to the E6 system, the reductions were 22 and 15% respectively.

In relation to TN (Figure 2), the highest values were found under the E6 system, differing statistically from the other systems down to the 30-40 cm layer.

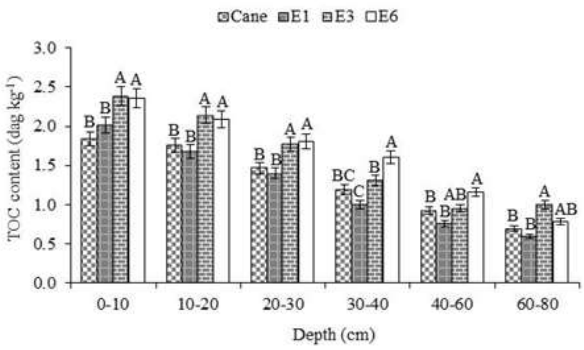

Figure 1 – Soil organic carbon content of the systems under sugarcane (Cane) and eucalyptus cultivation after one year (E1), three years (E3) and six years (E6) in the State of Alagoas. Similar letters at the same depth do not differ statistically by Tukey's test ($p < 0.05$).

Figura 1 *– Teor de carbono orgânico do solo nos sistemas sob cana-de-açúcar (Cane) e cultivos de eucalipto com 1 ano (E1), 3 anos (E3) e 6 anos (E6), no estado de Alagoas. Letras iguais na mesma profundidade não diferem estatisticamente pelo teste de Tukey (p < 0,05).*

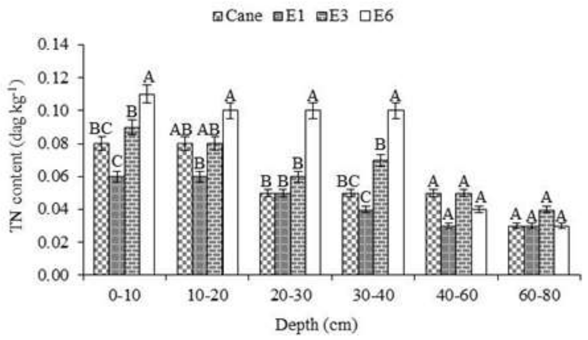

Figure 2 – Total soil nitrogen content of the systems under sugarcane (Cane) and eucalyptus cultivation after one year (E1), three years (E3) and six years (E6) in the State of Alagoas. Similar letters at the same depth do not differ statistically by Tukey's test ($p < 0.05$).

Figura 2 *– Teor de nitrogênio total do solo nos sistemas sob cana-de-açúcar (Cane) e cultivos de eucalipto com 1 ano (E1), 3 anos (E3) e 6 anos (E6), no estado de Alagoas. Letras iguais na mesma profundidade não diferem estatisticamente pelo teste de Tukey (p < 0,05).*

The TN content seen under the Cane and E3 systems was intermediate, and did not differ for the layers under study. The lowest TN content was seen in E1 for all evaluated layers, showing reductions of 44, 41, 42 and 64% when compared to E6 in the 0-10, 10-20, 20-30 and 30-40 cm layers respectively.

It can be seen in Table 2 that the WMD showed a significant difference between systems ($p < 0.05$) in the 0-10, 10-20 and 30-40 cm layers, the lowest values at these layers being seen under the Cane system. The GMD differed statistically ($p < 0.05$) between agricultural systems only in the first layer of soil (0-10 cm), where the lowest values were seen in the area of sugarcane. In contrast to the results found for WMD and GMD, for the same layer, the ASI had the lowest value under the E1 system, with no difference from Cane or E3, but significantly lower (11.2%) when compared to E6.

Table 3 shows the groups of cropping systems formed by the Tocher method, taking into account all the variables in the study (physical and chemical). The result of the cluster analysis showed that there is a clear distinction between the area of sugarcane and the areas of eucalyptus up to a depth of 20 cm; whereas from this level, only the area of eucalyptus after six years (E6) stands out from others.

4. DISCUSSION

The greater values for bulk density found under the Cane, E1 and E3 systems can be attributed to destabilisation of the soil structure. Under the Cane system, conventional tillage and the traffic of agricultural machines during cultivation probably had this effect, furthermore, straw burning and the consequent reduction in the amount of organic residue in the soil may also have contributed to this behaviour (Carneiro et al., 2009). In the E1 and E3 areas of eucalyptus, such behaviour probably reflects the approximately 20 years of monocropped sugarcane that preceded cultivation of the eucalyptus, resulting in less aggregation and an increase in BD. Under the E6 system, although the area had previously been cultivated with sugarcane, the results indicate that the six years without machine traffic and the continuous deposition of plant residue on the surface are already resulting in an improvement in the physical quality of the soil, and restoring the structure (Cruz et al., 2014; Costa et al., 2015).

The results for the content, and especially the stocks, of SOC evidenced three aspects. Initially, that the conversion of sugarcane cultivation with burning into eucalyptus resulted in a substantial increase in SOC, which had already occurred in the three-year-old area (E3); that the changes occur more clearly only

Table 2 – Mean values for weighted mean diameter (WMD), geometric mean diameter (GMD) and aggregate stability index (ASI) for the cropping systems and depths under evaluation.
Tabela 2 – *Valores médios do diâmetro médio ponderado (WMD), diâmetro médio geométrico (GMD) e índice de estabilidade de agregados (ASI) dos sistemas de cultivo e profundidades avaliadas.*

Layer(cm)	Cropping system			
	Cane	E1	E3	E6
		WMD (mm)		
0-10	1.65 aB	2.27 aA	2.54 aA	2.32 aA
10-20	1.75 aB	2.16 abAB	2.11 abAB	2.36 aA
20-30	1.86 aA	2.02 abA	2.04 bA	2.25 abA
30-40	1.87 aB	2.02 abAB	2.06 bAB	2.34 aA
40-60	2.04 aA	2.03 abA	1.94 bA	2.00 abA
60-80	1.88 aA	1.78 bA	1.69 bA	1.83 Ab
		GMD (mm)		
0-10	1.47 aB	1.54 aA	1.56 aA	1.55 aA
10-20	1.49 aA	1.52 abA	1.53 abA	1.54 aA
20-30	1.50 aA	1.50 abA	1.50 bA	1.53 aA
30-40	1.50 aA	1.51 abA	1.52 abA	1.55 aA
40-60	1.51 aA	1.52 abA	1.51 abA	1.51 aA
60-80	1.50 aA	1.48 bA	1.48 bA	1.51 aA
		ASI (%)		
0-10	82.97 aAB	78.98 bB	86.44 aAB	88.96 aA
10-20	82.56 aA	88.10 abA	87.45 aA	88.03 aA
20-30	85.46 aA	90.61 aA	92.49 aA	85.31 aA
30-40	85.12 aA	87.93 abA	90.16 aA	88.42 aA
40-60	91.62 aA	87.55 abA	89.94 aA	91.83 aA
60-80	91.19 aA	87.95 abA	87.89 aA	84.63 aA

Cane: sugarcane; E1: eucalyptus after one year, E3: eucalyptus after three years, E3: eucalyptus after six years. Mean values followed by the same uppercase letter in the rows and lowercase letter in the columns do not differ by Tukey's test at 5% probability.

down to a depth of 20-30 cm; and finally, that the E3 system presented a greater C content than did E6. The greater stocks in E3 and E6 are related to various factors, such as the lack of soil turning and the continuous supply of plant residue to the surface (Fracetto et al., 2012; Loss et al., 2014; Conceição et al., 2017), and to the microclimate formed by the forests, which reduces direct contact of the solar rays and rain drops with the soil and maintains a more uniform humidity and temperature, favouring development of the root system and of microbial activity in the surface layer, resulting in a reduction in the mineralisation of the SOM (Loss et al., 2014; Ibiapina et al., 2014; Mascarenhas et al., 2017). The beneficial results of growing eucalyptus, seen down to the 20 and 30 cm layers only, may be due to the short cultivation period in the areas of eucalyptus, but also to the supply of organic material from falling leaves, branches and bark from the trees, forming an organic layer and a higher density of fine roots, common in eucalyptus plantations (Neves, 2000; Pulrolnik et al., 2009). However, the greater stock of C in E3 compared to E6 can be partially explained by the greater soil density.

Table 3 – Grouping of the cropping systems (sugarcane and eucalyptus) by the Tocher method, based on the mean Euclidean distance, using the physical and chemical properties for each depth evaluated in the study.
Tabela 3 – *Agrupamento dos sistemas de cultivo (cana-de-açúcar e eucalipto), pelo método de Tocher, com base na distância euclidiana média, utilizando as propriedades físicas e químicas, em todas as profundidades avaliadas no estudo.*

Level (cm)	Group I			Group II	
0-10	Cane		E1	E3	E6
10-20	Cane		E1	E3	E6
20-30	CaneE1	E3	E6		
30-40	CaneE1	E3	E6		
40-60	CaneE1	E3	E6		
60-80	CaneE1	E6	E3		

Cane: sugarcane; E1: eucalyptus after one year, E3: eucalyptus after three years, E3: eucalyptus after six years.

In any case, the results are similar to those of other studies (Pulrolnik et al., 2009; Gatto et al., 2010; Rodrigues et al., 2013; Barreto et al., 2014; Ibiapina et al., 2014), where, in the layers under evaluation, increases in the levels of C and N were seen with an increase in the age of the eucalyptus crop, reaching values greater than those seen in soils under native forest. In this way, the results of this study show that the cultivation of eucalyptus, when properly managed, promotes over time a reduction in BD and recovery of the levels and stocks of C and N in the soil.

The lower values for the stocks and levels of C and N under the Cane and E1 systems can be explained. In the area of Cane, this is probably due to the intense practices of conventional management (e.g. biomass burning and soil preparation) adopted during cultivation of this crop (Vasconcelos et al., 2010). In the one-year area of eucalyptus (E1), in addition to the deep soil turning carried out when planting the eucalyptus, which exposes the organic material stored at the deeper layers of the soil to the attack of microorganisms, the slow replacement of plant residue due to the young age of the plants may also be contributing to this effect (Ibiapina et al., 2014; Mascarenhas et al., 2017).

Analysing the values for N stock throughout the soil profile (0-80 cm), a significant increase can be seen under the E6 system. The high values for N stock seen in the oldest area of Eucalyptus (E6) is possibly related to the greater proportion of woody material (mainly in the branches) deposited in the litter, and to the higher concentration of phenolic compounds, cellulose and lignin, with notably greater quantities of N (Pillon et al., 2011; Barreto et al., 2014). The variation in N values between systems may have occurred due not only to the age of the eucalyptus plantations, but also to the clay content and to environmental factors, especially temperature, humidity, soil type and relief (Rodrigues et al., 2013).

As seen, the results for soil aggregate stability (WMD, GMD and ASI) showed the best values under the Eucalyptus systems (E1, E3 and E6). According to Vasconcelos et al. (2010), the WMD represents the percentage of stable aggregates in the largest diameter class. The results of this study show values greater than 2 mm, demonstrating the predominance of macroaggregates in these areas, and proving that in areas with little or no soil turning aggregate sizes are larger (Ibiapina et al., 2014). This effect is due to the continuous supply of plant residue, a reduction in soil turning, and an increase in the stocks of C and N (Table 1). According to Loss et al. (2014), areas that have water-stable aggregates contribute to improvements in porosity, and consequently, greater infiltration and resistance to erosion. The lower values for WMD found in the first layers of the soil under the Cane system can be attributed to the loss of soil structure due to management (burning, a lower supply of organic matter, and turning) (Rossetti et al., 2014).

The trend seen by Fontana et al. (2010) confirms this study. Those authors studied aggregation indices and the relation to humic substances in the soil under forest, pasture and sugarcane, and found the highest value for WMD in the 0-40 cm layer of the forest in relation to the cropping systems. Ibiapina et al. (2014) found no statistical difference for WMD in the 0-30 cm layer between areas of native forest and of eucalyptus after 2 and 4 years; however, those areas differed significantly from the area under conventional soybean cultivation.

The GMD is an estimate of the aggregate class size with the highest occurrence within the cropping system under evaluation (Barreto et al., 2014). In this study, the values for GMD under the systems were less than 2 mm for each of the layers evaluated, indicating a tendency towards low aggregate stability (Rossetti et al., 2014). The lowest values for GMD were found under the Cane system down to the 10-20 cm layer, demonstrating that the intense soil turning resulted in the breakdown of macro and microaggregate structures; furthermore, the low clay content contributed to a loss of physical protection of the SOM (Ibiapina et al., 2014). However, the highest values for GMD seen in the areas of eucalyptus (E1, E3 and E6) in the 0-10 and 10-20 cm layers, confirms the information of other authors (Rodrigues et al., 2013; Barreto et al., 2014; Ibiapina et al., 2014), when they report that Eucalyptus plantations promote the recovery of the physical properties of the soil, increasing water storage capacity, reducing particle loss through erosion, and promoting the physical protection of the SOM (Vasconcelos et al., 2010).

The ASI is a measure of total soil aggregation, without considering distribution by aggregate class; therefore, the larger the quantity of aggregates <0.25 mm, the smaller the ASI (Ibiapina et al., 2014). The lowest value for ASI in this study was seen in the surface layer (0-10 cm) under the E1 system (79%), which means that in this layer, 79% of the aggregates under this system obtained by dry sieving did not remain intact when sieved in water. This effect is possibly associated with the period prior to the establishment of the crop, when the area was submitted to conventional soil preparation during the sugarcane monocrop, also with the low production of plant residue due to the young age of the eucalyptus plants. According to Coutinho et al. (2010), unstable aggregates on the surface tend to disappear and disperse under the impact of raindrops. However, the highest value for ASI at this layer was seen under the E6 system; undoubtedly, this effect occurred due to the area being in balance, with the greater aggregation prevailing, similar to that found by other authors (Barreto et al., 2014; Ibiapina et al., 2014; Loss et al., 2014).

In general, the better aggregation indices (WMD, GMD and ASI) seen in the areas of eucalyptus confirm the great potential of these plantations when properly managed to promote the recovery of soil aggregation over time, which is of great importance for soil conservation, as it contributes to greater resistance to the erosion process, protection of the SOM, high microbial activity, and consequently greater increases of C and N in the soil.

The results of the cluster analysis contributed to reinforcing the other results, demonstrating that the effects of adopting eucalyptus in areas of sugarcane are apparent in the more superficial layers of the soil (up to 20 cm). The results also suggest that the cultivation period of the eucalyptus influences the soil attributes, differentiating the oldest system (E6) from the other systems down to the 60 cm layer.

5. CONCLUSIONS

The conversion of sugarcane cultivation under conventional tillage and with straw burning into eucalyptus plantations, promoted an increase in the levels and stocks of carbon and nitrogen, the water stability of aggregates and the aggregation indices of the soil. In addition, it reduced bulk density.

The cluster analysis contributed to confirming the difference between the sugarcane and eucalyptus in the surface layers, but also showed a tendency for the oldest eucalyptus crop to differ from the other crops at the deeper layers, indicating that the time factor has been determinant in changing the soil attributes.

The results indicate that the conversion of sugarcane into eucalyptus in the Atlantic Forest region of the State of Alagoas may represent an alternative for promoting carbon sequestration and improving soil quality. However, further studies in areas with longer cultivation times are necessary to confirm the results.

6. REFERENCES

Barreto PAB, Gama-Rodrigues EF, Gama-Rodrigues AC. Carbono das frações da matéria orgânica em solos sob plantações de eucalipto de diferentes idades. Scientia Forestalis. 2014;42(104):581-90.

Carneiro MAC, Souza ED, Reis EF, Pereira HS, Azevedo WR. Atributos físicos, químicos e biológicos de solo de Cerrado sob diferentes sistemas de uso e manejo. Revista Brasileira de Ciência do Solo. 2009;33(1):147-57.

Companhia Nacional de Abastecimento - Conab. Cana-de-açúcar. Safra 2016/ 2017. Terceiro levantamento dezembro de 2016. v.3. [acessado em: 29 jan. 2017]. Disponível em: http:// http:// www.conab.gov.br/OlalaCMS/uploads/arquivos/16_12_27_16_30_01_boletim_cana_portugues_-3o_lev_-_16-17.pdf

Conceição MCG, Matos ES, Bidone ED, Rodrigues RAR, Cordeiro RC. Changes in soil carbon stocks under integrated crop-livestock-forest system in the Brazilian Amazon region. Agricultural Sciences. 2017;8(9):904-13.

Corrêa RM, Freire MBGS, Ferreira RLC, Silva JAA, Pessoa LGM, Miranda MA, et al.. Atributos físicos de solos sob diferentes usos com irrigação no semiárido de Pernambuco. Revista Brasileira de Engenharia Agrícola e Ambiental. 2010;14(4):358-65.

Costa NR, Andreotti M, Lopes KSM, Yokobatake KL, Ferreira JP, Pariz CM, et al. Atributos do solo e acúmulo de carbono na integração lavoura-pecuária em sistema plantio direto. Revista Brasileira de Ciência do Solo. 2015;39(3):852-63.

Coutinho FS, Loss A, Pereira MG, Rodrigues Junior DJ, Torres JLR. Estabilidade de agregados e distribuição do carbono em Latossolo sob sistema plantio direto em Uberaba, Minas Gerais. Comunicata Scientiae. 2010;1(2):100-5.

Cruz DLS, Vale Júnior JF, Cruz PLS, Cruz ABS, Nascimento PPRR. Atributos físico-hídricos de um Argissolo Amarelo sob floresta e Savana naturais convertidas para pastagem em Roraima. Revista Brasileira de Ciência do Solo. 2014;38(1):307-14.

Empresa Brasileira de Pesquisa Agropecuária - Embrapa. Manual de métodos de análise de solos. 2ª. ed. Rio de Janeiro: Centro Nacional de Pesquisa de Solos; 1997. 212p.

Empresa Brasileira de Pesquisa Agropecuária - Embrapa. Zoneamento agroecológico do estado de Alagoas - ZAAL. 2012. [acessado em: 14 de mar. de 2017]. Disponível em: http://www.uep.cnps.embrapa.br/zaal/imagens/MapasSolos/Solos_Sao%20Miguel.jpg.

Fontana A, Brito RJ, Pereira MG, Loss A. Índices de agregação e a relação com as substâncias húmicas em Latossolos e Argissolos de Tabuleiros Costeiros, Campos dos Goytacazes, RJ. Revista Brasileira de Ciências Agrárias.2010;5(3):291-7.

Fracetto FJC, Fracetto GGM, Cerri CC, Feigl BJ, Siqueira Neto M. Estoques de carbono e nitrogênio no solo cultivado com mamona na Caatinga. Revista Brasileira de Ciência do Solo. 2012;36(5):1545-52.

Gatto A, Barros NF, Novais RF, Silva IR, Leite HG, Leite FP, et al. Estoques de carbono no solo e na biomassa em plantações de eucalipto. Revista Brasileira de Ciência do Solo. 2010;34(4):1069-79.

Ibiapina TVB, Salviano AAC, Nunes LAPL, Mousinho FEP, Lima MG, Soares LMS. Resistência à penetração e agregação de um Latossolo Amarelo sob monocultivo de soja e de eucalipto no Cerrado do Piauí. Científica. 2014;42(4):411-8.

Instituto Brasileiro de Geografia e Estatística - IBGE. SIDRA – Banco de tabelas estatísticas. Produção da Extração Vegetal e da Silvicultura. [acessado em: 23 mar. 2017] Disponível em:http://www2.sidra.ibge.gov.br/bda/tabela/protabl.asp?c=5930&z=t&o=29&i=P

Loss A, Costa EM, Pereira MG, Beutler SJ. Agregação, matéria orgânica leve e carbono mineralizável em agregados do solo. Revista de la Facultad de Agronomía. 2014;113, (1):1-8.

Neves JCL. Produção e partição de biomassa, aspectos nutricionais e hídricos em plantios clonais de eucalipto na região litorânea do Espirito Santo [tsse]. Campos dos Goytacazes: Universidade Estadual do Norte Fluminense; 2000. 202p.

Marques JDO, Luizão FJ, Teixeira WG, Vitel CM, Marques EMA. Soil organic carbon, carbon stock and their relationships to physical attributes under forest soils in Central Amazonia. Revista Árvore. 2016;40(2):197-208.

Mascarenhas ARP, Sccoti MSV, Melo RR, Corrêa FLO, Souza EFM, Andrade RA, et al. Atributos físicos e estoques de carbono do solo sob diferentes usos da terra em Rondônia, Amazônia Sul-Ocidental. Pesquisa Florestal Brasileira. 2017;37(89):19-27.

Pegoraro RF, Silva IR, Novais RF, Barros NF, Fonseca S, Dambroz CS. Estoques de carbono e nitrogênio nas frações da matéria orgânica em Argissolo sob eucalipto e pastagem. Ciência Florestal. 2011;21(2):261-73.

Pillon CN, Santos DCS, Lima CLR, Antunes LO. Carbono e nitrogênio de um Argissolo Vermelho sob floresta, pastagem e mata nativa. Ciência Rural. 2011;41(3):447-53.

Pulrolnik K, Barros NF, Silva IR, Novais RF, Brandani CB. Estoques de carbono e nitrogênio em frações lábeis e estáveis da matéria orgânica de solos sob eucalipto, pastagem e Cerrado no Vale do Jequitinhonha - MG. Revista Brasileira de Ciência do Solo. 2009;33(5):1125-36.

Rao RC. Advanced statistical methods in biometric research. New York: John Wiley & Sons; 1952. 390p.

Rodrigues LS, Almeida TA, Marino RH, Barretto MCV, Martins MVG, Prata RM. Qualidade de solos cultivados com eucalipto em Itaporanga D´Ajuda – Sergipe. Revista Brasileira de Ciências Agrárias. 2013;8(1):95-101.

Rossetti KV, Teixeira DB, Reis IMS, Centurion JF. Agregação de um Latossolo em função de diferentes ciclos de cultivo de cana-de-açúcar sob colheita mecanizada. Revista Agro@mbiente. 2014;8(1):10-7.

Tedesco MJ, Gianello G, Bissani CA, Bohnen H, Volkweis SI. Análise de solo, plantas e outros materiais. 2ª. ed. Porto Alegre: Universidade Federal do Rio Grande do Sul; 1995. 174p.

Vasconcelos RFB, Cantalice JRB, Oliveira VS, Costa YDJ, Cavalcante DM. Estabilidade de agregados de um Latossolo Amarelo distrocoeso de Tabuleiro Costeiro sob diferentes aportes de resíduos orgânicos da cana-de-açúcar. Revista Brasileira de Ciência do Solo. 2010;34(2):309-16.

Yeomans JC, Bremner JM. A rapid and precise method for routine determimation of organic carbon in soil. Communications in Soil Science and Plant Analysis. 1988;19(13):1467-76.